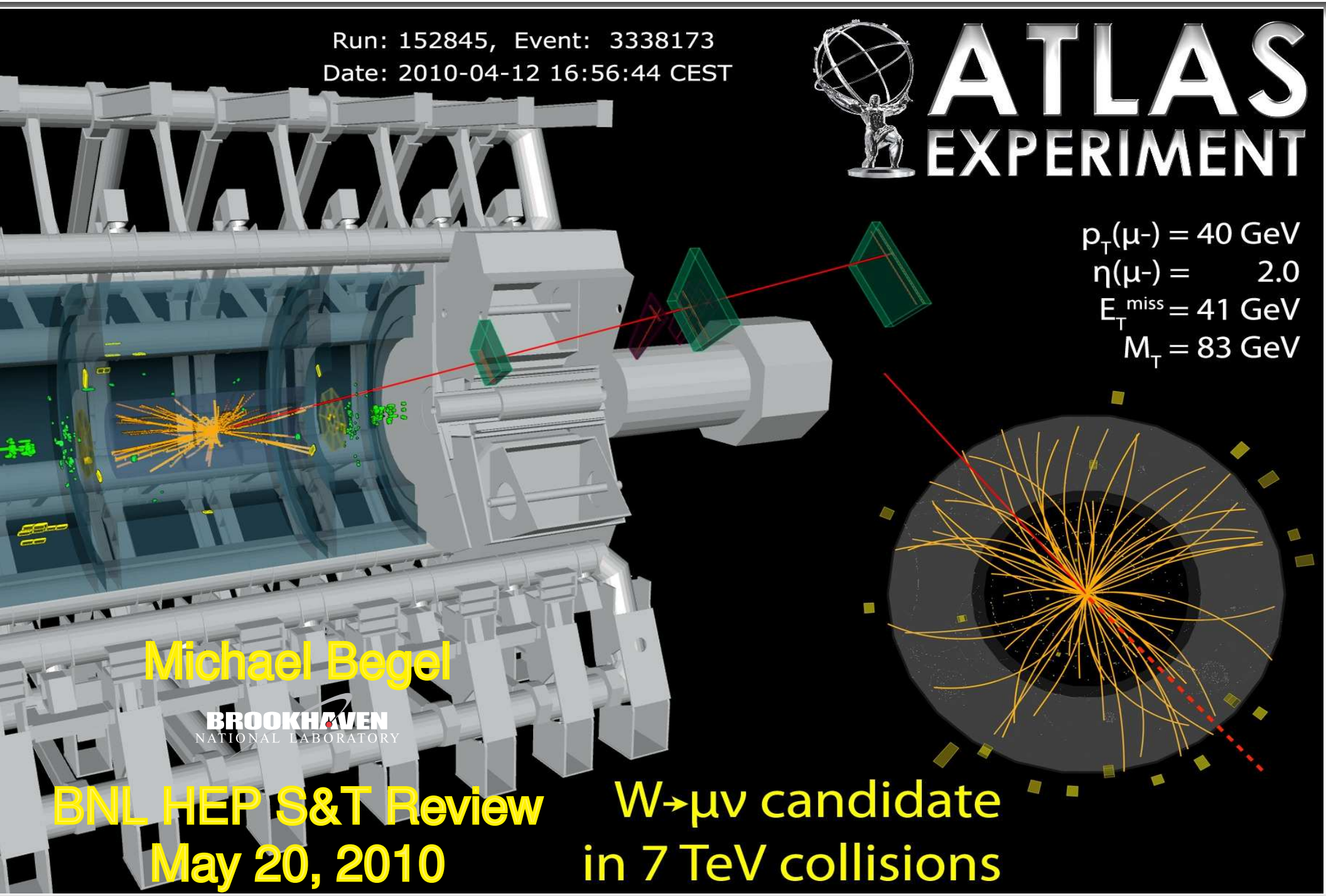
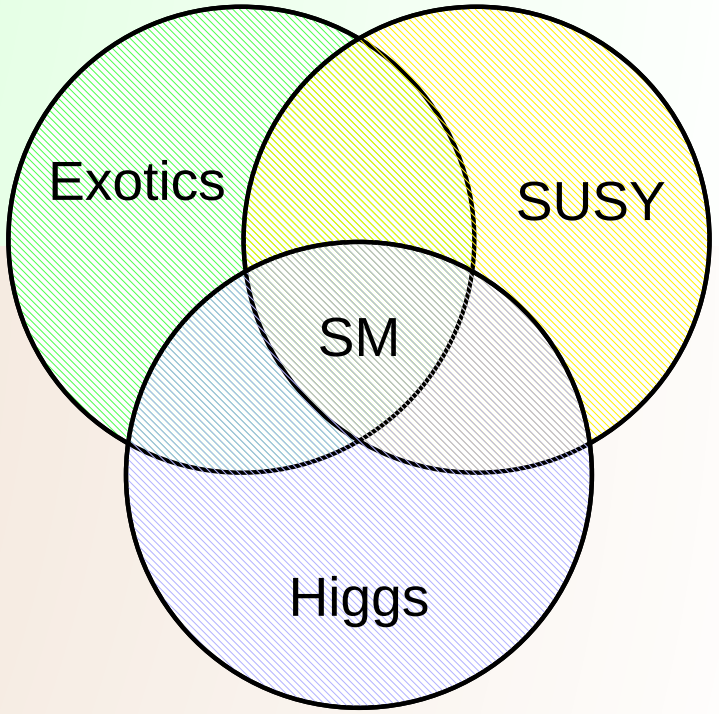
# BNL Contributions to ATLAS Physics



# BNL Physics Analysis on ATLAS

BROOKHAVEN NATIONAL LABORATORY

- BNL has built a strong foundation for physics analysis
  - extensive expertise in detector, software, and performance
  - lead analysis software tool development
- The physics prospects drive our efforts:
  - active in physics analysis since the beginning of ATLAS
  - performance activities lead directly into physics analyses
  - current focus is on the initial data
    - Standard Model physics
    - backgrounds to signatures of new physics
  - long-term interests are in searches for new physical phenomena




- Leadership roles:
  - Physics Group Co-Conveners
    - Higgs: Assamagan (2008–10)
    - SUSY: Redlinger (2009–11)
    - Heavy Ions: Steinberg‖ (2008–10)
  - U.S. ATLAS Physics Forums
    Redlinger (BSM/SUSY), Snyder (egamma)
  - Paper authors, editors, & reviewers
- Collaborative Activities:
  - work with U.S. and foreign institutions
  - productive collaborations with BNL theorists
  - BNL physicists supervise students from Iowa State, Johannesburg, Oregon

‖ supported by Nuclear Physics

# First Collisions to First Papers

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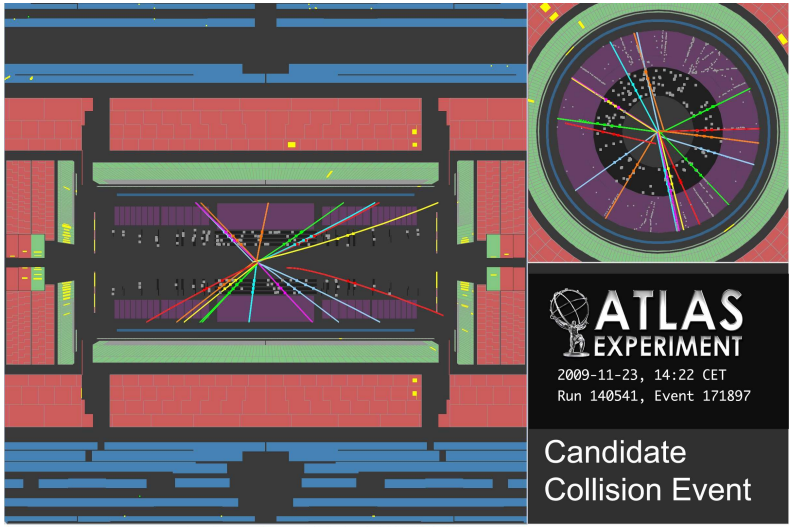
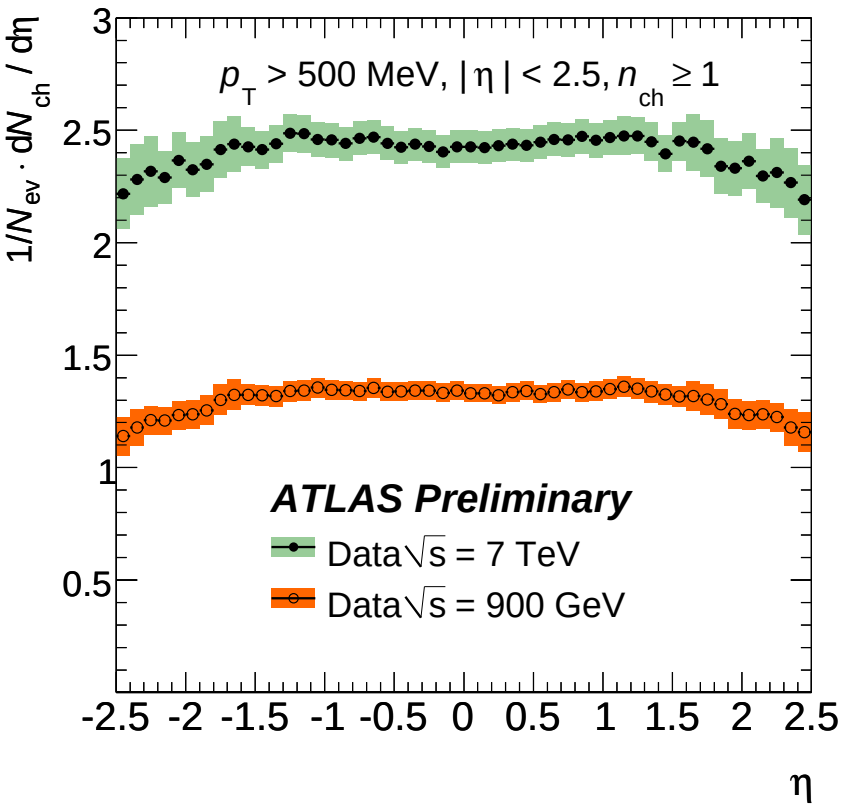
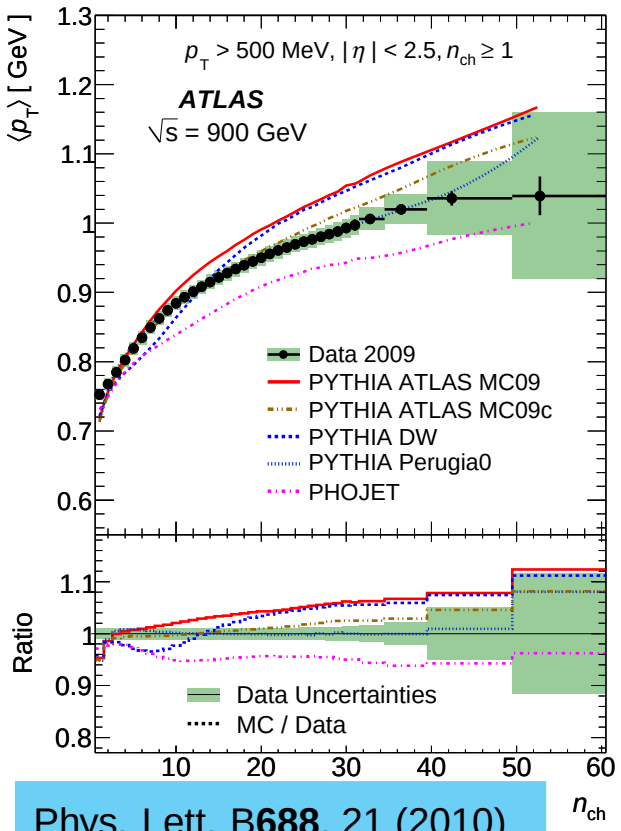
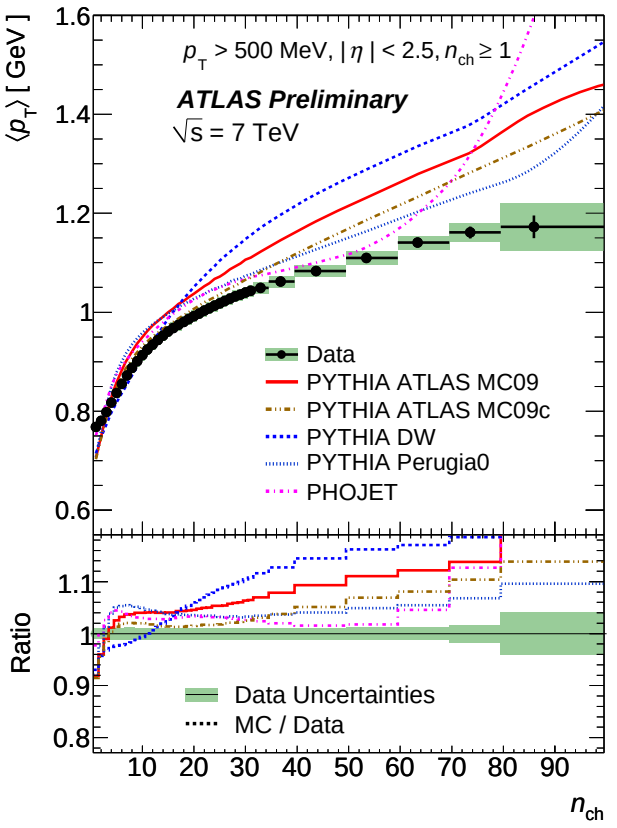
- First broad look at particle production in minimum bias reactions
  - important for understanding detector performance
  - crucial for tuning Monte Carlo event generators
  - BNL contributed to trigger efficiencies and comparisons with other experiments in collaboration with DESY, Freiburg, UC London
- Now measuring two-particle correlations between charged particles in collaboration with Glasgow

**Steinberg**‖




Phys. Lett. B**688**, 21 (2010)

# $\sqrt{s}$ = 7 TeV Physics Papers in 2010

BROOKHAVEN NATIONAL LABORATORY

$\mathcal{O}(1)$ nb$^{-1}$

*JetEtmiss*

Begel, Ma, Majewski, Paige†, Pleier

*Combined Muon*

Adams‡, Assamagan, Nikolopoulis, Yamamoto

*EGamma Performance*

Snyder, Tarrade

† supported by High Energy Theory
‡ supported by US ATLAS Operations
‖ supported by Nuclear Physics
___ graduate student (supervised by BNL personnel)
▢ lead analyzer or editor

# $\sqrt{s}$ = 7 TeV Physics Papers in 2010

BROOKHAVEN NATIONAL LABORATORY

$\mathcal{O}(1)$ nb$^{-1}$ $\mathcal{O}(10)$ nb$^{-1}$

*JetEtmiss*

Begel, Ma, Majewski, Paige†, Pleier

*Observation of Jets*

Begel, Majewski, Paige†

*Combined Muon*

Adams‡, Assamagan, Nikolopoulis, Yamamoto

*Observation of W / Z*

Assamagan, Nikolopoulis, Tarrade, Yamamoto

*EGamma Performance*

Snyder, Tarrade

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lead analyzer or editor

# $\sqrt{s}$ = 7 TeV Physics Papers in 2010

BROOKHAVEN NATIONAL LABORATORY

$\mathcal{O}(1)$ nb$^{-1}$ $\mathcal{O}(10)$ nb$^{-1}$ $\mathcal{O}(100)$ nb$^{-1}$

*JetEtmiss*

Begel, Ma, Majewski, Paige†, Pleier

*Observation of Jets*

Begel, Majewski, Paige†

*Azimuthal Decorrelations in Dijets*

Begel, Majewski, Paige†

*Combined Muon*

Adams‡, Assamagan, Nikolopoulis, Yamamoto

*Observation of W/Z*

Assamagan, Nikolopoulis, Tarrade, Yamamoto

*Inclusive $\mu$*

Adams‡, Redlinger

*EGamma Performance*

Snyder, Tarrade

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# $\sqrt{s}$ = 7 TeV Physics Papers in 2010

BROOKHAVEN NATIONAL LABORATORY

$\mathcal{O}(1)$ nb$^{-1}$ | $\mathcal{O}(10)$ nb$^{-1}$ | $\mathcal{O}(100)$ nb$^{-1}$ | $\mathcal{O}(1)$ pb$^{-1}$ | $\mathcal{O}(10)$ pb$^{-1}$

*JetEtmiss*

Begel, Ma, Majewski, Paige†, Pleier

*Observation of Jets*

Begel, Majewski, Paige†

*Azimuthal Decorrelations in Dijets*

Begel, Majewski, Paige†

*$W(\rightarrow \mu)$+jet cross section*

Redlinger

*Combined Muon*

Adams‡, Assamagan, Nikolopoulis, Yamamoto

*Inclusive $\mu$*

Adams‡, Redlinger

*$W'$ Search*

Adams‡

*Observation of W/Z*

Assamagan, Nikolopoulis, Tarrade, Yamamoto

*Observation of $t\bar{t} \rightarrow \ell\ell$*

Mete, Pleier, Protopopescu, Rajagopalan, Searcy, Snyder

*EGamma Performance*

Snyder, Tarrade

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# $\sqrt{s}$ = 7 TeV Physics Papers in 2010

BROOKHAVEN NATIONAL LABORATORY

$\mathcal{O}(1)$ nb$^{-1}$ | $\mathcal{O}(10)$ nb$^{-1}$ | $\mathcal{O}(100)$ nb$^{-1}$ | $\mathcal{O}(1)$ pb$^{-1}$ | $\mathcal{O}(10)$ pb$^{-1}$ | $\mathcal{O}(100)$ pb$^{-1}$

*JetEtmiss*
Begel, Ma, Majewski, Paige†, Pleier

*Observation of Jets*
Begel, Majewski, Paige†

*Azimuthal Decorrelations in Dijets*
Begel, Majewski, Paige†

*SUSY in j+ $\not{E}_T$*
Gibbard, Paige†, Redlinger

*SUSY in $\ell$ + j+ $\not{E}_T$*
Paige†, Redlinger, Snyder

*W($\rightarrow \mu$)+jet cross section*
Redlinger

*Combined Muon*
Adams‡, Assamagan, Nikolopoulis, Yamamoto

*W′ Search*
Adams‡

*$Z/\gamma^\star \rightarrow \mu\mu$ $p_T$*
Adams‡, Begel, Paige†, Yamamoto

*Inclusive $\mu$*
Adams‡, Redlinger

*Observation of W/Z*
Assamagan, Nikolopoulis, Tarrade, Yamamoto

*Observation of $t\bar{t} \rightarrow \ell\ell$*
Mete, Pleier, Protopopescu, Rajagopalan, Searcy, Snyder

*$WW \rightarrow \ell\ell$*
Gadfort, Ma, Pleier

*EGamma Performance*
Snyder, Tarrade

*$H \rightarrow ZZ^\star \rightarrow \ell\ell$*
Assamagan, Nikolopoulis, Tarrade

† supported by High Energy Theory
‡ supported by US ATLAS Operations
‖ supported by Nuclear Physics
___ graduate student (supervised by BNL personnel)
▢ lead analyzer or editor

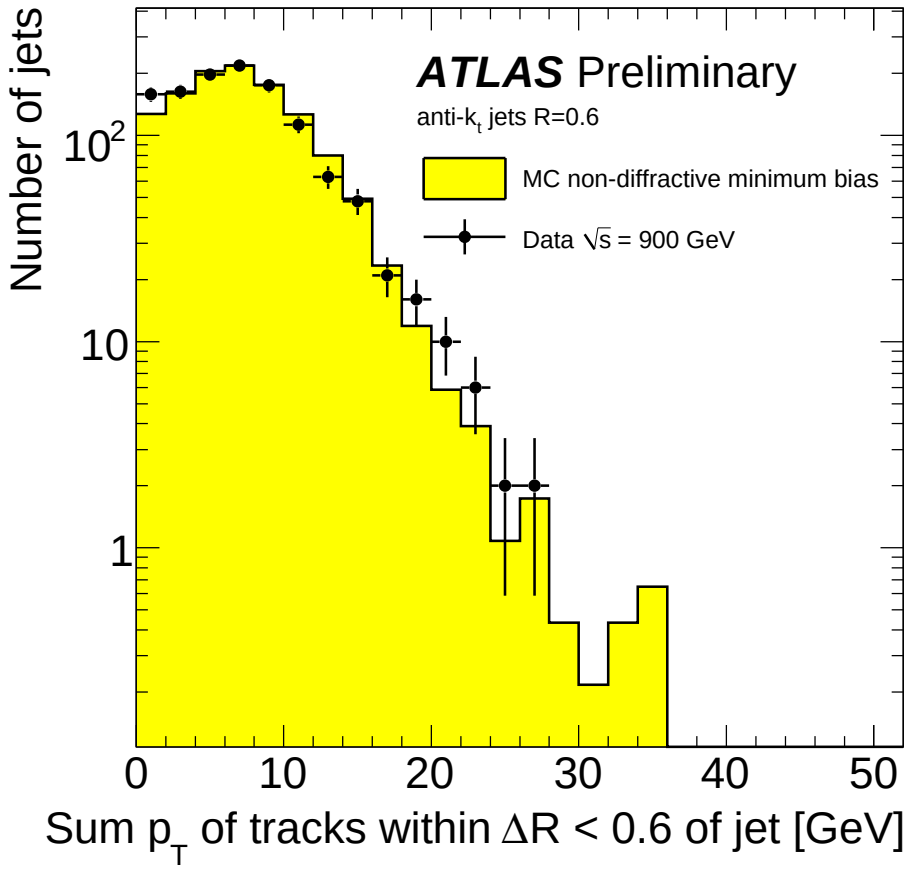
# JES with Tracks in Jets

**Begel, Ma, Paige†**

- It is critical to quickly establish the jet energy scale (JES) and determine its uncertainty for early jet physics measurements
- Initial JES [$\mathcal{O}(1)$ nb$^{-1}$] based on simulation with uncertainties extracted from data *vs.* simulation comparisons
- Data-based JES requires significantly more integrated luminosity [$\mathcal{O}(10)$ pb$^{-1}$]

- Use charged tracks to establish JES with respect to simulation:
  - fraction of jet energy in charged tracks well known:
    - hadronization takes place after DGLAP evolution
    - $p_T$ cut to remove underlying event
  - this method can extend JES to very high-$p_T$ jets
  - don't need high statistics; $\lesssim$ 5% JES up to 300 GeV with $\mathcal{O}(100)$ nb$^{-1}$
  - developed by BNL; collaborating with LBNL
  - will be included in initial estimate of JES as confirmation of overall uncertainty

connection with **Qiu** from BNL Nuclear Theory Group



# $\Delta\phi$ in Dijet Events

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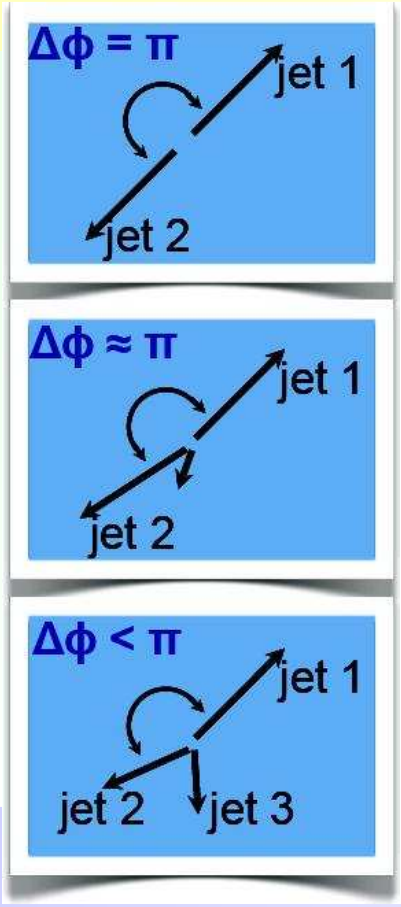
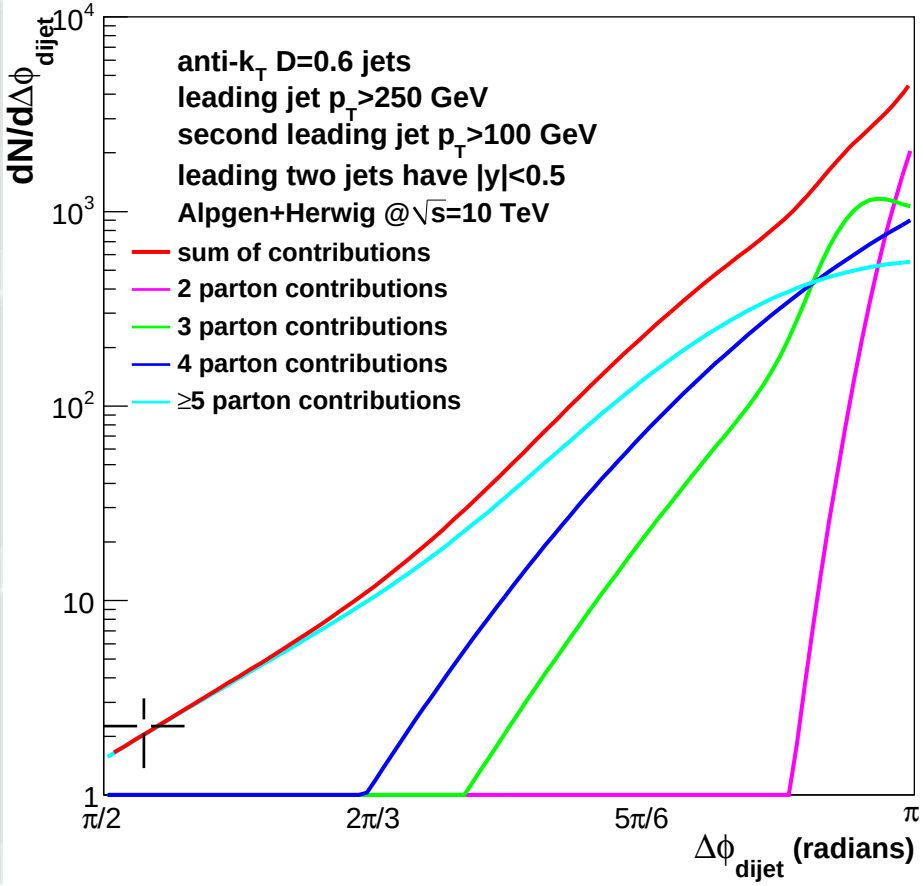
**Begel**, **Majewski**, **Paige**†

- Azimuthal angle between two leading central jets sensitive to higher-order QCD radiation without explicitly measuring additional jets
  - test pQCD up to $\mathcal{O}(\alpha_s^4)$
  - validate MC event generators such as Alpgen & Sherpa $\Rightarrow$ important for searches
  - input into Pythia tune
  - shape measurement (no uncertainty from luminosity or absolute efficiencies)
  - limited sensitivity to JES
- Initiated and led by BNL
- Collaborating with Louisiana Tech, SMU, Stony Brook, Toronto, UC London
  - working with 6 students
  - two Ph.D. theses (Stony Brook, Toronto)



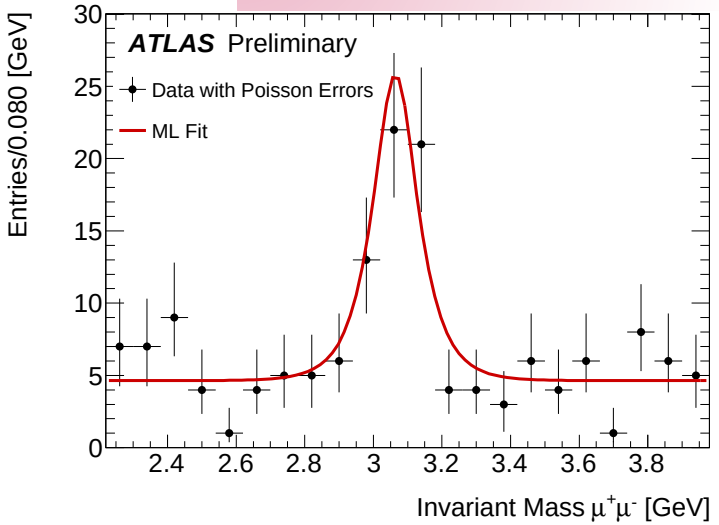

- Future Activities
  - re-analyze with precision JES and $[\mathcal{O}(100)\,\mathrm{pb}^{-1}]$
  - extend observable into SUSY search $[\mathcal{O}(0.1-1)\,\mathrm{fb}^{-1}]$

# Muon Production

BROOKHAVEN NATIONAL LABORATORY

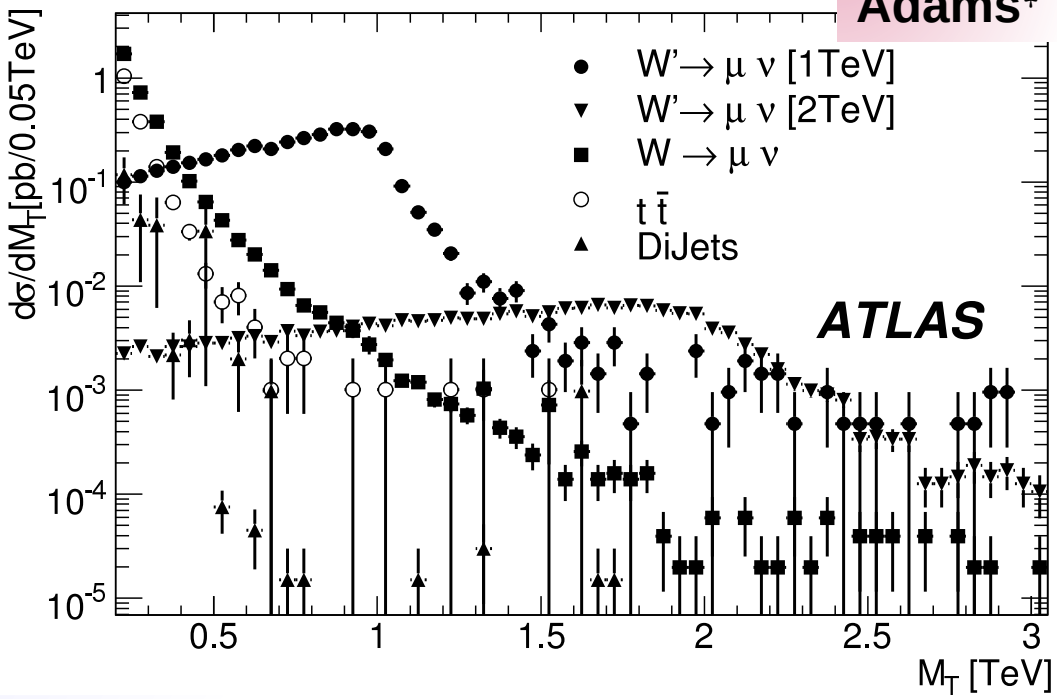
- The inclusive muon spectrum is key measure of performance and physics
  - single, double, and multiple muon spectra binned in several kinematic observables
  - interpret in terms of Standard Model processes
    - $c$, $b$, $W$, $Z/\gamma^{\star}$
    - model-independent search for new physical phenomena (high $p_T$ and $m_T$)
  - study correlations with $\not{E}_T$
  - in collaboration with LBNL & Rome

**Adams‡, Redlinger**




- $W'$ Search
  - BNL concentrating on $\mu$+ $\not{E}_T$ channel
  - contributing to measurements of muon trigger and reconstruction efficiency
  - studying mis-reconstructed muons that make a fake $W'$
  - Adams‡ is editor for this paper
  - in collaboration with Athens, CERN, Saclay, TRIUMF, Wisconsin

**Adams‡**



# Muon Production

BROOKHAVEN NATIONAL LABORATORY

**Redlinger**

- $W$+jets in the muon decay channel
  - heavy flavor backgrounds $\Rightarrow$ interesting for $\mu$+jet analyses including SUSY

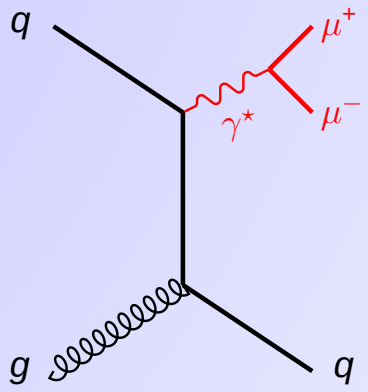
**Adams‡, Begel, Paige†, Yamamoto**

- $Z/\gamma^\star \rightarrow \mu^+\mu^-$ Production
  - $p_T$ spectrum sensitive to initial-state radiation
    - test pQCD
    - input for Pythia tunes
  - measure $d\sigma/dp_T$ in mass bins
  - collaborating with Iowa State; Yamamoto's Ph.D. thesis effort

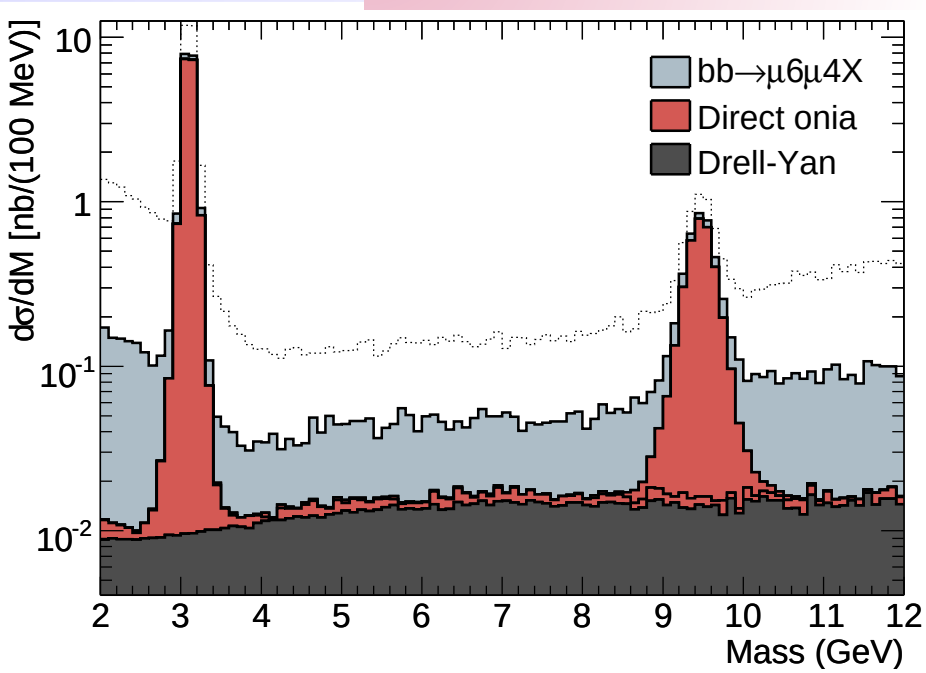
connection with **Kilgore** from BNL HEP Theory Group

**Adams‡, Begel, Paige†**

- High $p_T$ low-mass Drell-Yan equivalent to direct photons via $\gamma^\star \rightarrow \mu^+\mu^-$
  - $\gamma^\star$+jet provides clean calibration signal for low $p_T$ jets [$\mathcal{O}(200)\,\text{pb}^{-1}$]
  - $J/\psi$+jet useful for low $p_T$ jet JES




connection with **Kilgore** from BNL HEP Theory Group



# Dilepton $t\bar{t}$ Cross Section

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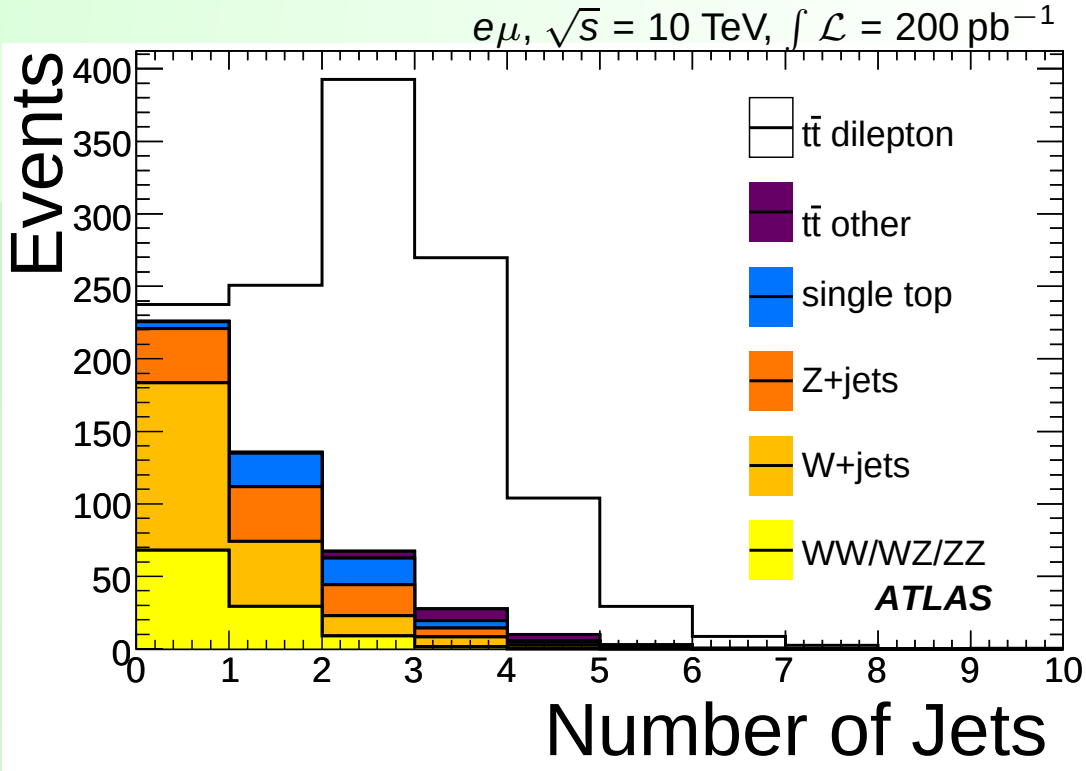
- The LHC is a top factory!
  - likely to see signatures of new physics
  - significant background to new physics (e.g., SUSY)
  - BNL experienced in top physics from our DØ efforts

**Assamagan**, Koch, Mete, **Patwa**, **Pleier**, **Protopopescu**, **Rajagopalan**, Searcy, **Snyder**

- BNL concentrating right now on dilepton decay channel
  - data quality, luminosity, trigger efficiency, fake rates, and impact of pile-up events
  - in collaboration with Bonn, Glasgow, Iowa State, UC Irvine, New York U., Oregon, Toronto, Stockholm, Yale
  - Mete's Ph.D. thesis effort




- Leverage experience with electrons, muons, and hadronic $\tau$'s
  $\Rightarrow$ increase sensitivity to new physics such as charged Higgs boson
  - lepton + isolated track
    - collaborating with Illinois & Oregon
    - Searcy's Ph.D. thesis effort
  - lepton + hadronic $\tau$
    - working on $\tau$ selection criteria
    - with Simon Fraser & LaTech

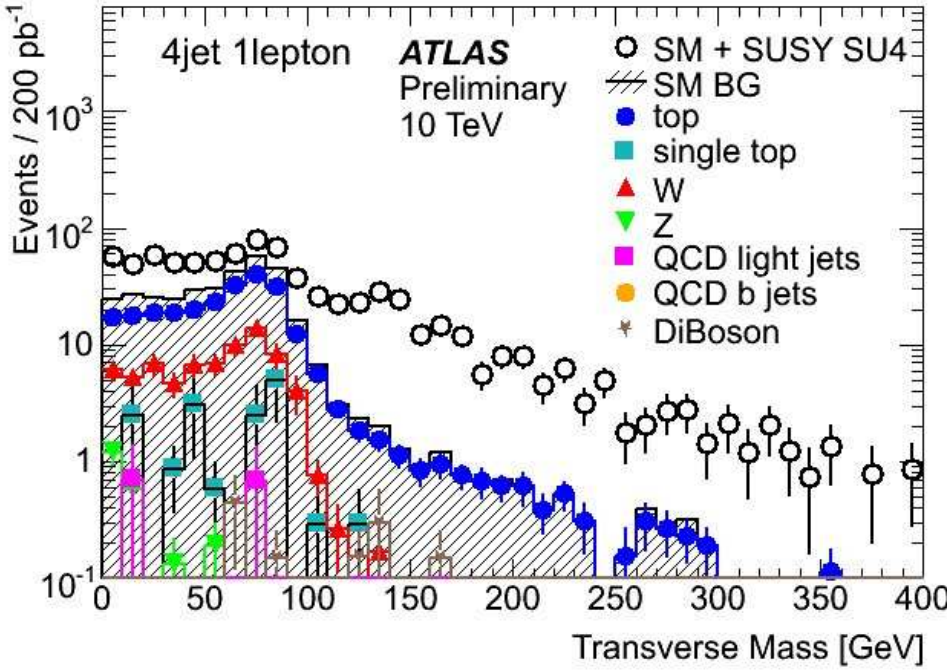
- Longer-term interests [$\mathcal{O}(1)$ fb$^{-1}$]:
  - search for $t\bar{t}$ resonances
  - test for lepton universality in $t\bar{t}$ decays; with Johannesburg — Koch's Ph.D. thesis effort

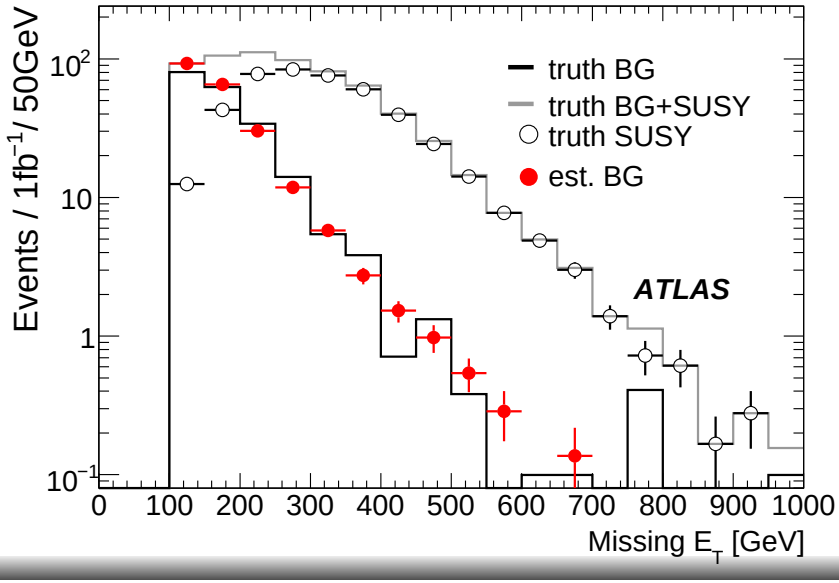
# Search for SUSY

BROOKHAVEN NATIONAL LABORATORY

- The search for SUSY has been a focus of BNL since earliest days of ATLAS
- Concentrate on $\ell$+jets+ $\not{E}_T$ channel
  - good reach prospects
  - better controlled background systematics
    *discovery sensitivity beyond Tevatron from 50 pb$^{-1}$ onwards*
- Study data-driven background methods:
  - $t\bar{t}$ in dilepton and $\ell$+jets decay channels
  - $\gamma$+jets to estimate $W$+jets background
  - estimate $\not{E}_T$ shape from heavy-flavor muon $p_T$ spectrum
  - in collaboration with Indiana
- Extend QCD dijet azimuthal decorrelation measurement to increase SUSY sensitivity in jets+$\not{E}_T$ channel
- Exploring collaboration with BNL theory group on $V$+jets production
  - understanding sources of theoretical uncertainties

*SUSY Group Co-Convener:* ***Redlinger***
**Begel**, **Majewski**, **Gibbard**, **Paige**†



# Dilepton WW

BROOKHAVEN NATIONAL LABORATORY

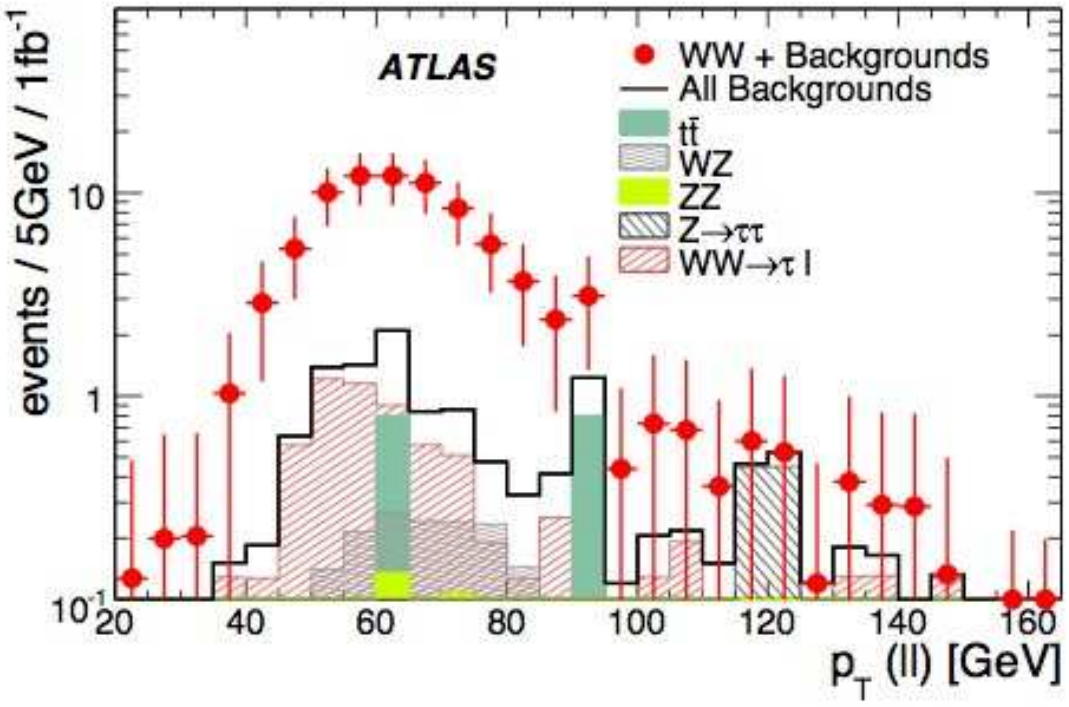
**Gadfort, Ma, Pleier**

- *WW* cross section is a key Standard Model measurement
  - important background for Higgs search
  - promising discovery potential through resonances and gauge couplings

- BNL concentrating on dilepton channel:
  - lepton fake rates (synergy with $t\bar{t}$ measurements)
  - exploring *b* jet veto to suppress $t\bar{t}$ backgrounds (utilizes expertise developed on DØ)
  - also looking into $\not{E}_T$ significance
  - working in collaboration with Columbia, Duke, Michigan
  - Ma edited the $\sqrt{s}$ = 14 TeV public note

- $\mathcal{O}(100)$ pb$^{-1}$: first cross section
- want $\mathcal{O}(1)$ fb$^{-1}$ for searches
- plan to introduce matrix element calculations developed on DØ for similar analysis
- long-term interest in jet reconstruction algorithms to identify highly boosted jets coming from *W* or *Z* decays

connection with **Davoudiasl** and **Soni** from BNL HEP Theory Group



# Search for the Higgs Boson

BROOKHAVEN NATIONAL LABORATORY

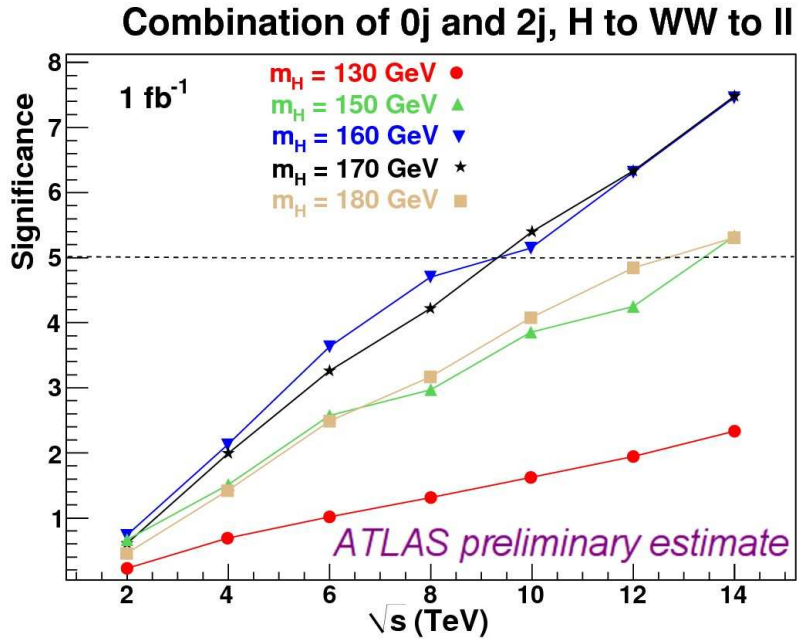
- The search for the Higgs Boson is a focus of our long-term plans for physics at ATLAS

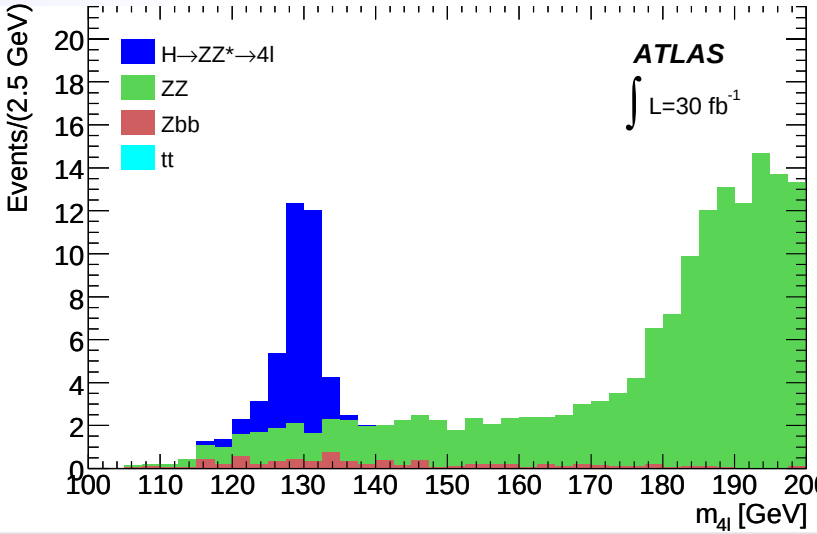
*Higgs Group Co-Convener:* ***Assamagan***
**Assamagan**, Lee, **Nikolopoulis**, **Patwa**, **Protopopescu**, **Tarrade**

- Near Term [up to $\mathcal{O}(1)\,\mathrm{fb}^{-1}$]
  - understand backgrounds to Higgs production
    - sensitivity studies for $H \to WW \to \ell\ell + \not{E}_T$
    - data-driven $Z \to \ell\ell$+fake leptons background estimation for $H \to ZZ \to \ell\ell\ell\ell$
  - Leptogenic SUSY
    - search in multi-lepton/multi-jet final states
    - viability of $H \to b\bar{b}$
    - in collaboration with Tufts & York
  - $H^{\pm} \to \chi^{\pm}\chi^{0} \to \ell\ell\ell + \not{E}_T$+jets
    - in collaboration with Arizona and Uppsala

- Medium/Long Term [$\mathcal{O}(1-2)\,\mathrm{fb}^{-1}$]
  - $H \to ZZ^{\star} \to \ell\ell\ell\ell$
    - includes search for $H \to Z'Z'$
    - in collaboration with Albany, ICTP, Indiana, Johannesburg, Yale
    - Lee's Ph.D. thesis effort
  - $H \to \tau\tau$
    - $Z \to \tau\tau$ is a significant background
    - studying data-driven background techniques
    - uses our DØ expertise in $\tau$ performance

connections with **Dawson** & **Kilgore** from BNL HEP Theory Group



# Summary



- BNL has successfully leveraged its long-term contributions to the detector, operations, software, and performance into a strong physics effort
  - recognized by ATLAS with co-convenership of 3 out of 8 physics groups:
    Higgs: Assamagan (2008–10) SUSY: Redlinger (2009–11) Heavy Ions: Steinberg[||] (2008–10)
  - chosen by ATLAS to edit and review papers
  - leading two high priority physics papers
    - Azimuthal Decorrelation in Dijet Events
    - Search for $W'$ Production
- ATLAS has demonstrated excellent detector performance with collision data at $\sqrt{s}$ = 0.9 and 7 TeV and is ready to explore the new energy frontier
- BNL well positioned to take advantage of FY10 – 11 data
  - experts in jet, electron, muon, and tau performance
  - access to BNL analysis & software expertise and computing resources has been invaluable for analyzing the early data
- We have formed strong collaborations for physics analysis
  - with 19 US institutions (44% of US ATLAS) and 17 foreign institutions
  - BNL analysis Jamborees provide a useful venue for developing collaborations
  - strong connections with BNL theorists
- The energy frontier is the most fertile ground for discovery physics in the coming decade
  - Exotics in dilepton final states
  - SUSY in $\ell$+jets+$\not{E}_T$ and jets+$\not{E}_T$
  - Higgs in $\ell\ell\ell$+ $\not{E}_T$+jets, $\ell\ell\ell\ell$, and $\tau\tau$ final states

# Additional Information

# Collaborating Institutions

BROOKHAVEN NATIONAL LABORATORY

## Institutions with which we actively collaborate on *physics analyses*

- State University of New York, Albany (Higgs)
- University of Arizona (Higgs)
- University of Chicago (Jets)
- Columbia University ($WW \to \ell\ell$)
- Duke University ($WW \to \ell\ell$)
- U. of Illinois, Urbana-Champagne ($t\bar{t} \to \ell$+track)
- Indiana University (SUSY, Higgs)
- Iowa State University ($Z/\gamma^\star \to \mu\mu$, $t\bar{t} \to \ell\ell$)
- University of California, Irvine ($t\bar{t} \to \ell\ell$)
- Louisiana Tech University (dijet $\Delta\phi$, $t\bar{t} \to \tau\ell$)
- LBNL (Jets, Muons)
- University of Michigan ($WW \to \ell\ell$)
- New York University ($t\bar{t} \to \ell\ell$)
- University of Oregon ($t\bar{t} \to \ell$+track)
- Southern Methodist University (dijet $\Delta\phi$)
- State University of New York, Stony Brook (dijet $\Delta\phi$)
- Tufts (Higgs)
- University of Wisconsin ($W'$)
- Yale ($t\bar{t} \to \ell\ell$, Higgs)

- Athens ($W'$)
- Bonn ($t\bar{t} \to \ell\ell$)
- CERN ($W'$)
- DESY (min bias)
- Freiburg (min bias)
- Glasgow (min bias, $t\bar{t} \to \ell\ell$)
- Johannesburg ($t\bar{t}$, Higgs)
- ICTP ($W'$)
- Rome (Muons)
- Saclay ($W'$)
- Simon Fraser ($t\bar{t} \to \tau\ell$)
- Stockholm ($t\bar{t} \to \ell\ell$)
- Toronto (dijet $\Delta\phi$,$t\bar{t} \to \ell\ell$)
- TRIUMF ($W'$)
- University College London (min bias, dijet $\Delta\phi$)
- Uppsala (Higgs)
- York (Higgs)